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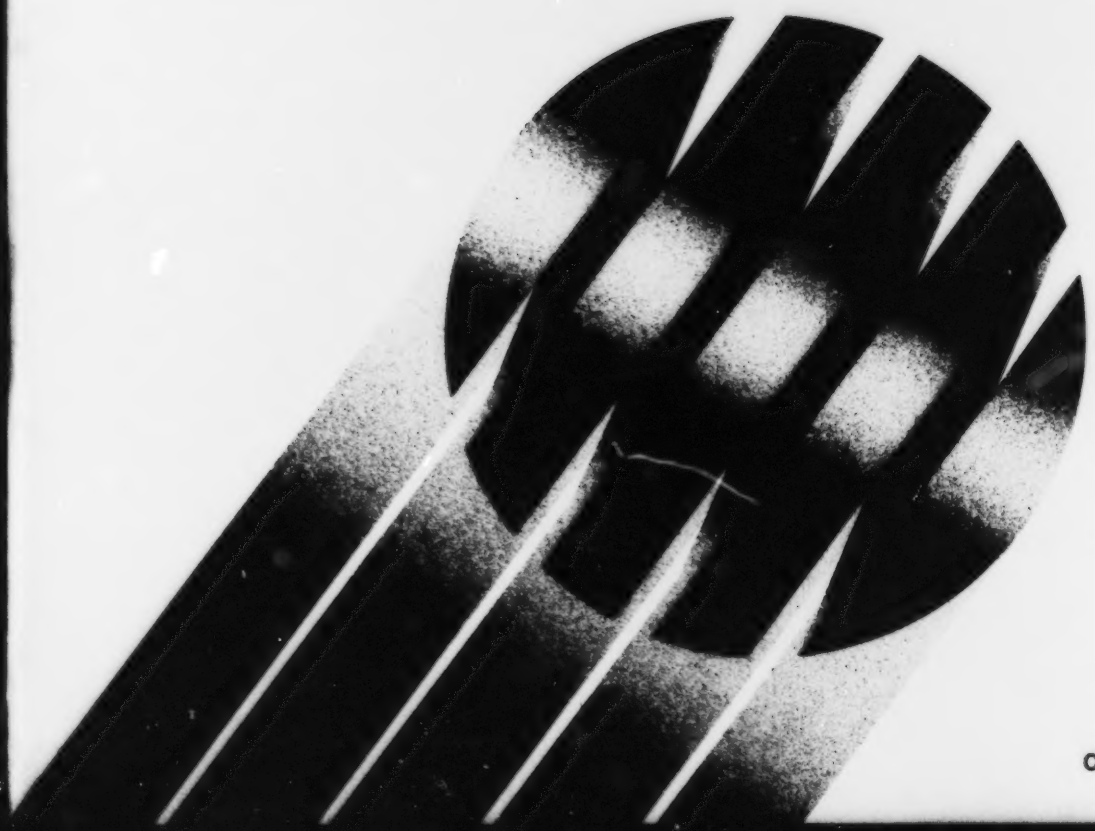
Summary Report No. 2: Celestite

R.K. Collings and P.R.A. Andrews
Mineral Sciences Laboratories



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SUMMARY REPORT NO. 2: CELESTITE

by

R.K. Collings* and P.R.A. Andrews**

Abstract

Celestite (strontium sulphate – $SrSO_4$) and strontianite (strontium carbonate – $SrCO_3$) are the two principal strontium minerals; the former is the more common and by far the chief commercial source of strontium.

More than 35 deposits or occurrences of celestite have been identified in Canada, chiefly in Newfoundland, Nova Scotia, New Brunswick, Ontario and British Columbia. Of particular economic interest are the Lake Enon and MacRae deposits in the Loch Lomond district of Cape Breton Island, N.S. The Lake Enon deposit was operated from 1969 to 1976 by Kaiser Celestite Mining Limited, which supplied an upgraded celestite concentrate to an associated strontium carbonate plant at Point Edward, near Sydney. The MacRae deposit is of current interest to Chromasco, a division of Timminco Limited, Haley, Ont., which is considering its possible development for strontium carbonate manufacture.

Celestite is used in the manufacture of strontium chemicals, principally strontium carbonate, nitrate, and hydroxide. Strontium chemicals, in turn, are used in the manufacture of glass and ceramics, in pyrotechnic devices, in the production of strontium metal and in other metallurgical applications.

Beneficiation of Nova Scotia celestite ores, which grade 50 to 60% $SrSO_4$, is necessary to upgrade the product to 90% $SrSO_4$, the feed grade required for strontium chemicals manufacture. Beneficiation consists chiefly of washing and flotation to remove undesirable clay, calcite and silica. The beneficiated strontium sulphate may be converted to the carbonate by a number of processes, the most economic being the "black ash," which involves chemical leaching, rotary kiln calcining with petroleum coke, washing, and treatment with carbon dioxide.

Celestite ores from the Lake Enon and MacRae deposits, as well from Birch Island, B.C., have been extensively studied by CANMET. Only the Nova Scotia deposits are summarized in this report since they are primary celestite ores; the Birch Island deposit is principally a fluorite ore containing secondary celestite. Studies on the Nova Scotia ores demonstrate the technical feasibility of developing the Loch Lomond deposits, in particular, as viable sources of strontium sulphate for strontium chemicals manufacture.

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RAPPORT N° 2 : GISEMENTS DE CÉLESTINE

par

R.K. Collings* et P.R.A. Andrews**

Résumé

La célestine (sulfate de strontium – $SrSO_4$) et la strontianite (carbonate de strontium – $SrCO_3$) sont les deux principaux minerais de strontium. La célestine, variété plus commune, constitue, de loin, la principale source commerciale de strontium.

Plus de 35 gisements de célestine ont été identifiés au Canada, en particulier à Terre–Neuve, en Nouvelle–Écosse, au Nouveau–Brunswick, en Ontario et en Colombie–Britannique. Les gîtes de Lake Enon et de MacRae, dans le district de Loch Lomond, Île–du–Cap–Breton, N.–É., semblent les plus rentables. Le gisement de Lake Enon a été exploité de 1969 à 1976 par la Kaiser Celestite Mining Limited qui a fourni un concentré de célestine enrichi à une installation de traitement de carbonate (strontianite) située à Point Edward, près de Sydney. Le gisement de MacRae présente un intérêt particulier pour Chromasco, une division de Timminco Limited, Haley (Ontario), qui envisage son exploitation en vue de produire de la strontianite.

La célestine sert à la fabrication de produits chimiques composés principalement de carbonate (strontianite), de nitrate de strontium et d'hydroxyde (strontiane). Les produits chimiques composés de strontium, quant à eux, sont utilisés pour la fabrication du verre, de céramiques et de dispositifs polytechniques. Ils servent également à la production de métal et à d'autres applications métallurgiques.

La valorisation de la célestine en provenance de la Nouvelle–Écosse, contenant du $SrSO_4$ dans une proportion de 50 à 60 %, est nécessaire afin d'obtenir un produit contenant du $SrSO_4$ dans une proportion de 90 % pour la fabrication des produits chimiques à base de strontium. La valorisation de la célestine consiste dans le lavage et la flottation du minerai afin d'en éliminer la glaise, le calcite et la silice. Le sulfate de strontium enrichi peut être transformé en carbonate par un certain nombre de procédés, le plus rentable étant "la cendre noire" qui comprend la lixiviation chimique, la calcination avec du coke de pétrole, le lavage, et le traitement au monoxyde de carbone.

Les minerais de strontium, provenant des gisements de Lake Enon et de MacRae de même que de Birch Island, C.–B., ont fait l'objet d'une étude exhaustive de la part de CANMET. Le rapport ne fait mention que des gisements de la Nouvelle–Écosse parce qu'ils sont constitués principalement de célestine. Le gisement de Birch Island consiste, en général, de fluorine contenant de la célestine secondaire. Les études des minerais en provenance de la Nouvelle–Écosse démontrent la faisabilité technique du développement des gisements de Loch Lomond, en particulier, en tant que sources de sulfate (célestine) pour la fabrication de produits chimiques à partir de strontium.

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INTRODUCTION

A 1983 CANMET survey of Canadian industrial mineral producers (1) identified a number of problems specific to the industrial mineral segment of the Canadian mineral industry, as well as potential opportunities for further development and expansion. The response to this survey, and discussions with industry and government officials, identified a requirement for information in a number of areas, including mineral deposits, past and current beneficiation studies, new developments, and information on product specifications and potential markets for Canadian industrial minerals.

In response to this requirement, and in light of the fact that CANMET has been directly involved in R&D studies on mineral samples from many of the industrial mineral deposits of Canada, a decision was made to compile related information on file in CANMET and EMR generally and, as available, from provincial government offices and the private sector, in a series of Summary Reports on a number of industrial minerals. Separate reports for each mineral would contain information pertaining to mineral occurrences, deposits of specific interest, current activities, product uses and specifications, process technology, and summaries of past R&D on specific deposits. This report, *Summary Report No. 2: Celestite*, is the second in this series.

STRONTIUM MINERALS

Mode of Occurrence

Celestite (strontium sulphate – $SrSO_4$) and strontianite (strontium carbonate – $SrCO_3$) are the two principal strontium minerals, the former being the more abundant in nature and by far the chief commercial source of strontium.

Many of the commercially important celestite deposits have been formed by concentration and precipitation of strontium in circulating solutions as they pass through or over sedimentary rock formations such as limestone, dolomite and marl. Other gypsum or anhydrite–associated occurrences are regarded as having been deposited in bedded form from seawater. Occasionally celestite occurs as a gangue mineral in lead–zinc veins.

In general the mode of occurrence of celestite and strontianite closely resembles that of barite and witherite ($BaCO_3$). Mineralogically, celestite closely resembles barite, the two minerals having the same crystal habit, hardness, colour, and general outward characteristics. The specific gravity of barite, at 4.5, is somewhat higher than celestite, at 4.0. Celestite, with 56.4% SrO, occurs in compact massive form, as interlacing fibrous aggregates, and in clear tabular crystals. The massive and fibrous varieties are commonly white or blue, whereas modular masses may be coated with a yellow iron oxide stain.

PRINCIPAL CELESTITE OCCURRENCES

Dawson (2) has catalogued more than 37 celestite occurrences or deposits in Canada and has recorded production, although mostly minor, from no fewer than eight deposits. These occurrences are chiefly in Newfoundland, Nova Scotia, New Brunswick, Ontario and British Columbia. Most are of limited economic interest, the chief exceptions being the Lake Enon and MacRae deposits in the Loch Lomond area of Cape Breton Island, N.S. Among the minor deposits, the fluorite/celestite deposit at Birch Island, B.C., has received varied attention in the past. These deposits are noted on the map, Figure 1, and are briefly described below.

Fig. 1 – Principal celestite deposits in Canada

Lake Enon

The Lake Enon celestite deposit, located 50 km southwest of Sydney, Cape Breton Island, was developed and operated by Kaiser Celestite Mining Limited from 1969 to 1976. During that period, about 300 000 t of ore were mined from several open pits and a further 25 000 t from an experimental underground mine. The ore was concentrated in a 500 tpd plant at the mine site, and the celestite concentrate, averaging 90% $SrSO_4$, was shipped to Kaiser Strontium Products Limited, a subsidiary operation at Point Edward, near Sydney, for conversion into strontium carbonate and other strontium chemicals, including strontium nitrate and hydroxide.

The Lake Enon celestite occurs in five distinct horizons in beds of varying thickness and is interlayered with limestone, shale, siltstone and gypsum. Top-quality ore may grade 85 to 95% celestite, with 2 to 3% iron oxide and 4 to 5% combined calcite and dolomite; however, the Lake Enon ore, as mined, usually contained only 35 to 65% $SrSO_4$. Mill feed typically analyzed 50 to 60% $SrSO_4$, 14 to 30% SiO_2, 10 to 20% $CaCO_3$, 1.5 to 2.0% $BaSO_4$, 0.5 to 5.0% Fe_2O_3, and 0.5 to 5.0% Al_2O_3 (3). Ore variability caused many problems at the concentrator and resulted in high reagent consumption and low concentrate grade and recovery. Concentrate grade frequently dropped below the 90% $SrSO_4$ specified by the Point Edward conversion plant. These problems, along with a general downturn in strontium markets, eventually resulted in the closure of both the concentrator at Lake Enon and the conversion plant at Point Edward in 1976.

MacRae

The MacRae celestite deposit, located 2 km northeast of the Lake Enon concentrator, was discovered by Kaiser Celestite Mining Limited in 1973. An open pit was established and approximately 85 000 t of ore were extracted before the cessation of mining operations in 1975. The MacRae celestite occurs in four distinct zones interlayered with conglomerate, limestone and gypsum sediments. The two central zones are of interest from the standpoint of grade and size. Felderhof (4) estimates that these zones contain more than 400 000 t of ore, grading 54% $SrSO_4$. He notes that additional surface reserves are possible and believes that underground reserves are extensive.

During the last few years, Chromasco, a division of Timminco Limited, has been studying the MacRae deposit with a view to re-establishing celestite mining, concentration and conversion to strontium carbonate on Cape Breton Island. Chromasco operates a non-ferrous metallurgy plant at Haley, near Renfrew, Ont., for the production of high-purity magnesium, calcium and strontium metals and alloys. This company is the only manufacturer of strontium metal in North America.

Other

Apart from the Lake Enon and MacRae deposits, Felderhof (4) rates several other celestite deposits in the same area as having a significant potential for development, e.g., the Amac, MacIntyre, Shaw and Monument properties. In New Brunswick, a one million tonne reserve of barite and celestite occurs at Upper Dorchester, near Moncton (5). The deposit is bedded or stratiform in nature and thus more likely to contain significant reserves. Other deposits of potential interest are the Ronan deposit in the Port-au-Port area of western Newfoundland (6), an occurrence in the West Bay area of Richmond County, Cape Breton Island, and the fluorite/celestite deposit at Birch Island in south-central British Columbia (7). These occurrences are noted on the map, Figure 1, and tabulated in Table 1 along with other prospects.

TECHNOLOGY

Celestite, strontium sulphate, is the principal commercial ore mineral for the manufacture of strontium chemicals, e.g., strontium carbonate, nitrate and hydroxide. As previously noted, Canada was at one

Table 1 – Celestite deposits and occurrences (2, 4, 6)

Province	Region	Location	Remarks
Newfoundland	Port-au-Port Peninsula	Gillams Cove	Celestite occurs intermixed with barite, calcite and aragonite in a host limestone breccia. Reserves have been estimated at 18 000 t, grading 12.5% celestite/barite in a 60/40 mix.
		Ronan (Hooper's Brook)	Celestite/barite interbedded with limestone. Reserves of celestite/barite have been estimated at 152 000 t; percentage of barite is greater than in Gillams Cove deposit. Some development of deposit.
		Boswarlos	Minor occurrence.
		Aguathuna	Minor occurrence.
Nova Scotia	Loch Lomond, Cape Breton Island	Lake Enon	Operated by Kaiser Celestite Mining Limited from 1969 to 1976; 325 000 t of ore mined, beneficiated, and concentrate converted to strontium carbonate at Point Edward plant. Ore is in five distinct horizons and interbedded with limestone, shale, siltstone and gypsum. Mill feed averaged 35 to 65% $SrSO_4$. Remaining reserves have been estimated at 400 000 t grading 50 to 55% $SrSO_4$.
		Amac	This deposit was explored by Kaiser Celestite in the mid-1970s. Reserves, in five zones, have been estimated at 95 000 t grading 57% $SrSO_4$, 16% SiO_2, 15% $CaCO_3$ and less than 1% $BaSO_4$. The deposit is covered by 10 to 35 m of overburden.

Table 1 (cont'd)

Province	Region	Location	Remarks
		MacRae	Deposit was operated for a short period in 1975–76 by Kaiser Celestite. Ore occurs in four distinct zones interlayered with conglomerate, limestone and gypsum. Central two zones that are available for mining contain an estimated 400 000 t grading 54% $SrSO_4$. Deposit is currently being studied by Chromasco with a view to development.
		Blaze Trail (MacIntyre)	High–grade celestite ore found in overburden. One drill hole by Kaiser Celestite analyzed 35% $SrSO_4$ and 1.5% $BaSO_4$.
		Shaw	High–grade float sample analyzed 82% $SrSO_4$ and 3.9% $BaSO_4$.
		Monument	High–grade float sample analyzed 95% $SrSO_4$ and 1.7% $BaSO_4$.
	West Bay	West Bay area, Richmond County	This area is geologically similar to the Loch Lomond area and is host to a number of celestite occurrences, many discovered by Kaiser Celestite and Imperial Oil Limited in 1970–71. Overburden ranges up to 35 m in thickness. Reserves of high–quality celestite at depth (±270 m) may approach 10 million t.
	Rear Black River		A river outcrop analyzed 85 to 90% $SrSO_4$ and 3% $BaSO_4$; however, a nearby drill hole showed only low–grade material running 20 to 25% $SrSO_4$.

Table 1 (cont'd)

Province	Region	Location	Remarks
	Frenchvale, Sydney River	Cape Breton North, Cape Breton County	Work by Kaiser Celestite in 1974 showed the Frenchvale occurrence to be low grade, 65% $SrSO_4$ with 10% or more $BaSO_4$. Samples from a Sydney River occurrence graded 80 to 95% $SrSO_4$ with 3 to 6% $BaSO_4$; however, beds were narrow and of limited lateral extent.
	Byer's Brook (Grant Prospect)	Guysborough County	Celestite deposits outcrop on the banks of a small stream. Analyses of two samples showed 59% $SrSO_4$ and 1.9% $BaSO_4$; 93% $SrSO_4$ and 1.3% $BaSO_4$.
	Beckwith	Cumberland County	Deposit consists of thin veins of celestite intermixed with brown sandstone and blue clay. Grab samples of float analyzed 86 to 89% $SrSO_4$ with up to 3% $BaSO_4$. Approximately 500 t were removed in 1987 by Chromasco for beneficiation and conversion studies. Although additional ore remains, the high clay to celestite ratio, heavy overburden, and wet ground conditions discourage further development.
New Brunswick	Eastern N.B., near Moncton	Upper Dorchester	This property has been drilled for both celestite and barite. Strontium outcrops are high grade; however, grade at depth is lower, being only 34% $SrSO_4$ in one hole. Limestone is the principal impurity with associated barite. Property was explored in 1971 by Dorbeck Syndicate and Canadian Merril Limited by geochemical and geophysical surveys and by diamond drilling.

Table 1 (cont'd)

Province	Region	Location	Remarks
Quebec	Southern Que., west of Montreal	Oka	Veins of strontianite ($SrCO_3$) have been reported in the Oka carbonatite complex; however, this occurrence is of little commercial interest.
Ontario	Renfrew County, Bagot Township	9 km southeast of Calabogie	About 200 t of celestite ore were mined at this property in 1918–20. Minor tonnages were sold for use in paint and rubber. Celestite occurs intermixed with marble at shallow depths. Stockpile sample analyzed 78.5% $SrSO_4$, 18.6% $BaSO_4$ and 0.7% $CaSO_4$.
	Leeds County, Lansdowne Township	20 km north of Gananoque, near Lyndhurst	Occurrence is in the form of a 25 to 50 cm vertical vein in marble, average grade reported to be 98% $SrSO_4$.
	Carleton County, Fitzroy Township	Galetta, 60 km west of Ottawa	Similar to the Lyndhurst occurrence. A sample of dump material analyzed 93% $SrSO_4$.
	Frontenac County, Loughborough Township	Verona, 40 km north of Kingston	Deposit consists of loosely intergrown crystals of barytocelestite in brecciated limestone. Sample analyzed 76% $SrSO_4$, 15% $BaSO_4$ and 7% $CaCO_3$.
British Columbia	South–central part of province	Birch Island, 130 km north of Kamloops	This property is of principal interest as a uranium deposit; however, significant quantities of associated fluorite and celestite occur. Reserves have been estimated a 1.8 million t of fluorite grading 29% CaF_2 and 230 000 t of celestite grading 15% $SrSO_4$.

time an important world supplier of strontium chemicals. These were produced by Kaiser Celestite Products Limited at Point Edward, Cape Breton Island, using celestite concentrate from Lake Enon and, more recently, MacRae ores.

The Lake Enon and MacRae ores were difficult to treat owing to the faulted and brecciated nature of the ore zones, which usually resulted in delivery of a low–grade feed to the concentrator. Ore grades reportedly ran 50 to 60% $SrSO_4$, which are low compared to world resources; for example, in Mexico and Germany, ore grade usually averages more than 85% $SrSO_4$.

Beneficiation of the Lake Enon ore was researched by various groups in the 1970s including Kaiser Celestite, CANMET, the Technical University of Nova Scotia, the Atlantic Industrial Research Institute and others (8, 9, 10). The process used by Kaiser, summarized in the flow diagram, Figure 2, included ore selection in the pit followed by crushing, sizing, washing and flotation at the Lake Enon concentrator. This resulted in a concentrate grading 88 to 92% $SrSO_4$ for delivery to the Point Edward chemical plant.

More recent beneficiation studies of the MacRae ore were initiated in 1986 by Chromasco and carried out largely by Lakefield Research, Lakefield, Ont. The results of these studies are summarized in a report of this work (11) and in the flow diagram, Figure 3. An initial trommel–screen washing step was recommended to free and remove adhering mud, followed by stage crushing, screening, grinding and flotation; the celestite float would be preceded by a sulphide float to remove metallic sulphides. The final concentrate achieved in pilot–plant trials by Lakefield Research averaged 90% $SrSO_4$.

The celestite concentrate from Lake Enon was converted into strontium carbonate at Kaiser Strontium Products' Point Edward plant by the "black ash" process. In this process, celestite concentrate, grading 90% $SrSO_4$, was leached with hydrochloric acid to remove calcium and magnesium carbonates, washed free of acid, blended with petroleum coke, and calcined in a rotary kiln to form a strontium sulphide calcine. The calcine was quenched, leached with water to dissolve the sulphide, and filtered; the filtrate was then treated with carbon dioxide to form strontium carbonate. These reactions are summarized in the following two equations:

$$SrSO_4 + 2C \rightarrow SrS + 2CO_2 \qquad \text{Eq 1}$$

$$SrS + CO_2 + H_2O \rightarrow SrCO_3 + H_2S \qquad \text{Eq 2}$$

In the noted recent studies by Chromasco, two principal routes for the production of strontium chemicals were considered, namely, the "black ash" and "white ash" processes. The black ash process appears to be the most economic and would probably be chosen by Chromasco should production of strontium chemicals be reinitiated using MacRae celestite concentrates. The hydrogen sulphide produced in the black ash conversion process could be used for the coproduction of elemental sulphur by the Claus process.

USES AND SPECIFICATIONS

Celestite is used in the production of a variety of strontium chemicals including carbonate, nitrate, oxide and sulphide. These, in turn, are used in the manufacture of glass and ceramics, in pyrotechnic devices, and in various metallurgical applications.

Strontium carbonate is an important additive in the production of glass used in face plates for colour televisions, where it absorbs potentially harmful X–ray emission. The carbonate is also used in

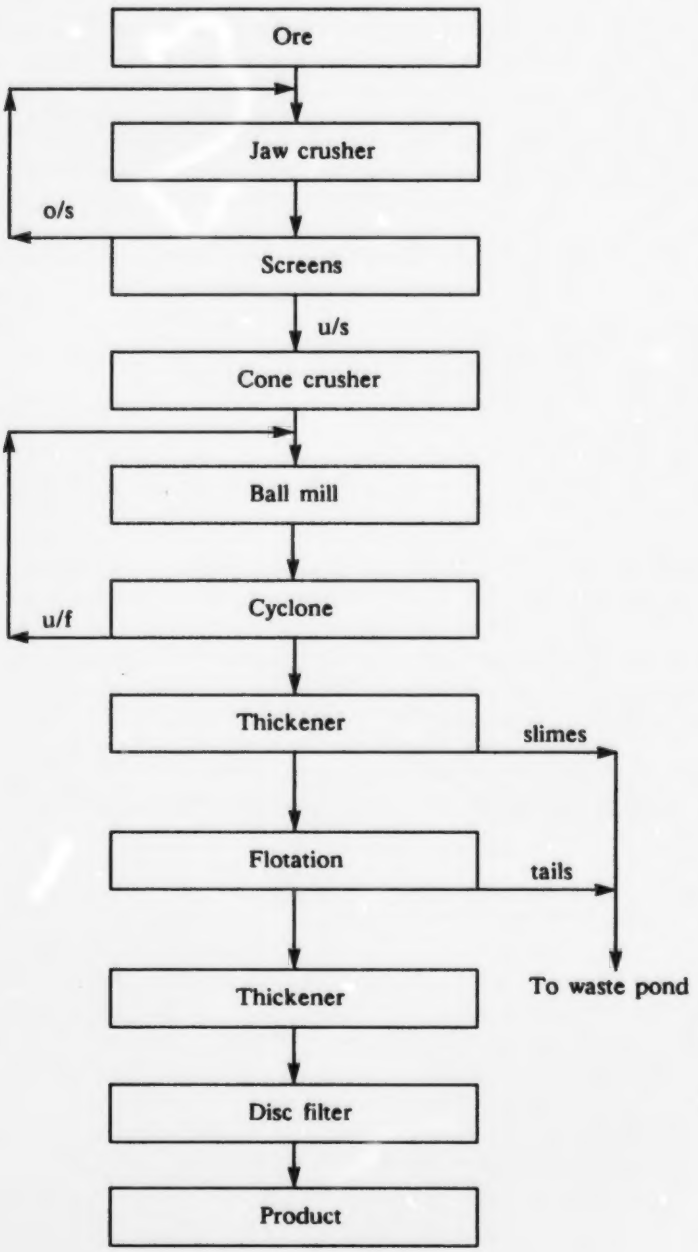

Fig. 2 – Flow diagram, Kaiser Celestite Mining Limited, Lake Enon ore

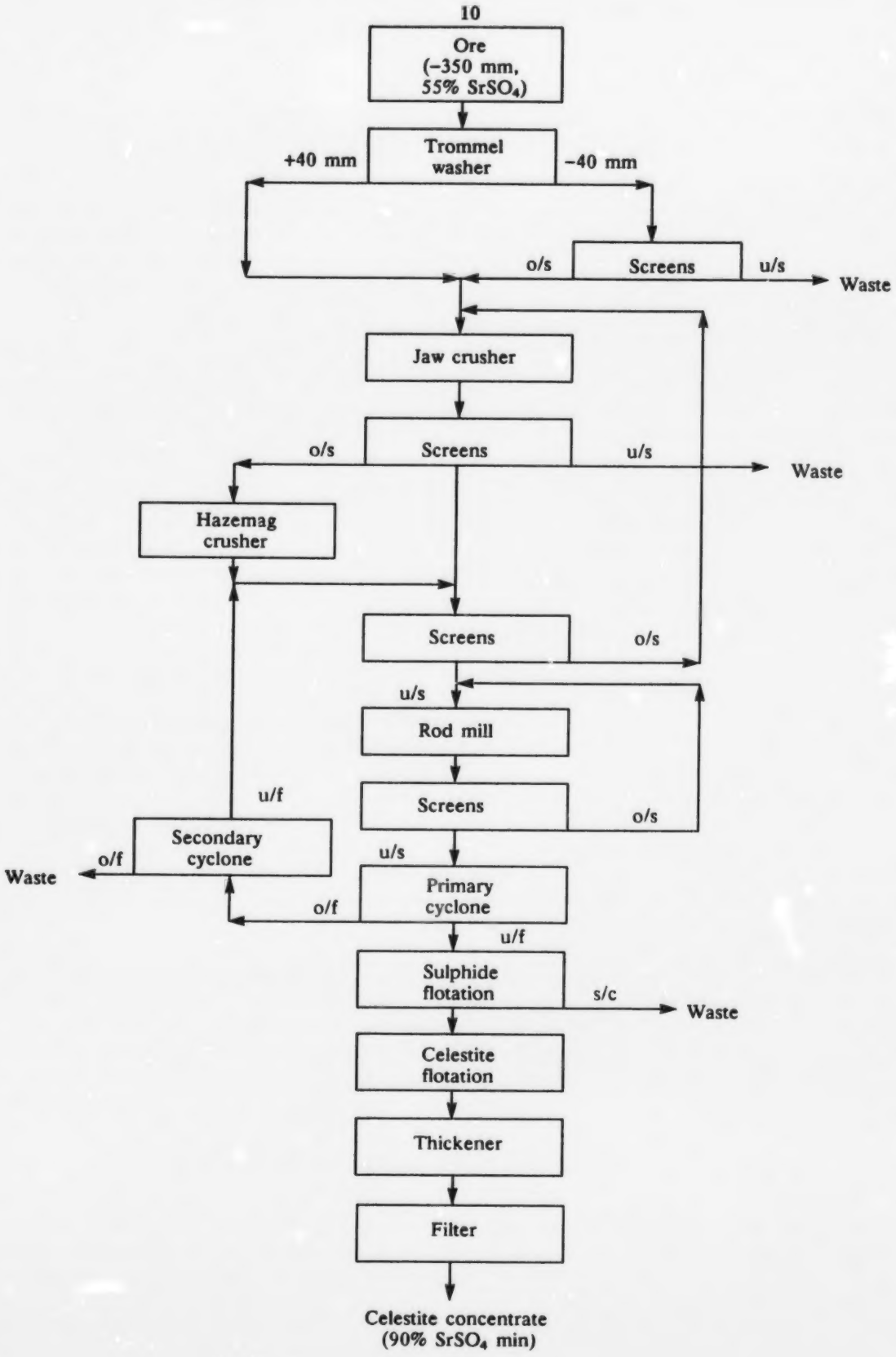

Fig. 3 – Proposed flow diagram, Chromasco, MacRae ore

ceramic ferrites for small permanent magnets for electric motors and electrical and electronic circuits, in the production of iridescent and specialty glass, and in the manufacture of strontium metal. Strontium carbonate finds limited but specialized use as a filler in rubber, plastics and paint.

Strontium nitrate is an important chemical in the manufacture of safety flares and fireworks, where it produces a brilliant red colour. Strontium oxide is used in ceramic coatings and glazes, and strontium sulphide and chromate find application in paint manufacture.

Strontium metal is used in the manufacture of strontium alloys which, in turn, are used to remove gas from vacuum tubes, as metal scavengers in metal purification processes, and as trace additives to increase the hardness of lead and copper.

Typical consumer specifications for celestite concentrate used in the manufacture of strontium carbonate and nitrate are shown in Table 2. Specifications for strontium carbonate used in metal, glass and electronic applications are noted in Table 3.

CURRENT INTEREST

There has been no Canadian production of celestite concentrates and chemicals since Kaiser Celestite closed its mining and concentrator operations near Lake Enon and strontium products plant at Point Edward in 1976.

Present Canadian requirements for strontium carbonate are supplied principally by the United States and Europe, with the chief consumer being Chromasco, the sole producer of strontium metal in North America. The United States, in turn, is dependent on imports of celestite and other strontium minerals from Mexico and Germany. In 1986, for example, the United States imported an estimated 16 500 t of strontium minerals and 3000 t of strontium compounds. Strontium carbonate and other compounds are produced in the United States by several companies, but principally by Chemical Products Corporation of Cartersville, Georgia.

There is considerable current interest in re–establishing Canadian production of both the sulphate and carbonate for domestic markets and for export to the United States. This interest, chiefly by Chromasco, centres around the MacRae celestite deposit. A smaller, higher grade deposit near Pugwash (Beckwith), N.S., is also of interest, particularly to provide material for strontium metal manufacture by Chromasco.

In 1986, Chromasco was awarded a contract under the Canada/Nova Scotia Mineral Development Agreement to investigate the beneficiation of MacRae celestite ore and its conversion to strontium carbonate. Following a review of the results, a decision will be made by Chromasco whether or not to proceed with the development of the MacRae deposit, the refurbishing of the concentrator plant at Lake Enon, and the construction of new conversion facilities in Sydney.

BENEFICIATION STUDIES

Seven studies were conducted on celestite ores in the Industrial Minerals Laboratory, CANMET, and in other laboratories between 1945 and 1987. The provinces represented were Nova Scotia and British Columbia, the main deposits being Lake Enon, MacRae, and Birch Island. All studies reported in the Appendix refer to Lake Enon and MacRae deposits since they are the only ones considered as primary celestite ores; the remaining four studies, conducted at CANMET, were concerned with secondary concentration of celestite after primary concentration of fluorite. As such, detailed summaries of these latter studies appear in *Summary Report No. 3: Fluorite* (12).

Table 2 – Celestite concentrate specifications for strontium carbonate and strontium nitrate manufacture

	Strontium carbonate (wt %)	Strontium nitrate (wt %)
$SrSO_4$	90 to 95	95 min
$BaSO_4$	1 to 2	2 max
SiO_2	1 to 2	n.a.
Fe_2O_3	0.4 to 0.5	n.a.
PbO	low	n.a.
F	0.1 max	n.a.
$CaSO_4$	2.0 max	1.5 max
$CaCO_3$	0.5 max	1.5 max
Free moisture	2.0 max	1.5 max
Particle size	−4.8 mm +840 μm	

n.a. – not available
Ref: "Strontium," *Industrial Minerals and Rocks*, 5th Edition, Vol 2, 1983.

Table 3 – Strontium carbonate specifications for strontium metal, glass and electronics manufacture

	Metal (wt %)	Glass (wt %)	Electronics (wt %)
$SrSO_4$	99.0 min	96.0 min	96.0 min
$BaCO_3$	1.0 max	3.0 max	1.5 max
$CaCO_3$	0.2 max	0.5 max	n.a.
$MgCO_3$	0.2 max	n.a.	n.a.
Na_2CO_3	0.15 max	1.0 max	n.a.
SO_2	0.08 max	0.4 max	0.4 max
Fe_2O_3	0.01 max	0.01 max	n.a.

n.a. – not available
Ref: "Strontium," *Industrial Minerals and Rocks*, 5th Edition, Vol 2, 1983.

Since the noted celestite studies were concerned mainly with flotation, a summary of principal parameter data is reported in Table 4, with reagent concentration data in Table 5. Information concerning research on Lake Enon and MacRae ores, conducted at other laboratories, is also included.

Scale of Investigation

Laboratory–scale studies of celestite ore from Cape Breton were conducted by CANMET and Lakefield Research. Pilot–plant studies were carried out at the Technical University of Nova Scotia and by Lakefield Research. Studies conducted on Birch Island ore by CANMET were both laboratory and pilot–plant scale.

Head Sample Analyses

Celestite ore from the MacRae area analyzed 72.4% $SrSO_4$ and from the Lake Enon area, 55% $SrSO_4$ (8); celestite ore from Birch Island was lower grade, analyzing between 9.0 and 22.2% $SrSO_4$ (13, 14).

Mineralogy

The minerals identified in Cape Breton ores were principally celestite with quartz and calcite; minor minerals included mica, chlorite, dolomite, barite and iron oxides. It is believed that the barite and celestite form a solid solution in the crystal lattice.

Birch Island ore is essentially a fluorite/celestite mix with a complex variety of minor minerals, including quartz, feldspar, barite, apatite, bastnaesite (lanthanum carbonate), mica and base–metal sulphides. Radioactive minerals are also present. The celestite and fluorite occur as very fine intergrowths with 5 μm inclusions of bastnaesite.

Birch Island, B.C.

Before 1959, two studies of Birch Island ore were conducted to separate celestite from fluorite. A 1948 study attempted, with very little success, to separate celestite from fluorite by magnetic and heavy–media separation on several size fractions, from 210 to 44 μm (15). In an earlier study (14), partial success was obtained in concentrating celestite by tabling the pilot–plant fluorite rougher tails, which contained celestite. A concentrate analyzing 90.6% $SrSO_4$ was obtained, but with a recovery of only 12%. The first attempt at differential flotation was achieved by Wyman (13), who used a bulk sulphide float, followed by a celestite float which, in turn, was followed by a fluorite float. A celestite concentrate analyzing 81.1% $SrSO_4$ was obtained. A later flotation study (7) produced a celestite concentrate analyzing 84.5% $SrSO_4$, with a recovery of 78%.

Flotation of celestite was achieved using Nyton and Igepon T33 as collectors to float celestite. Sodium silicate was used as a slime dispersant and quartz depressant, and citric acid was a fluorite depressant. Generally a grind of 100% −75 to −44 μm was required to achieve liberation, and multistage cleaning was necessary for high–grade concentrates. Information was not reported regarding pH or pulp density; rougher flotation time in one study (7) was very fast, at 2 min.

Lake Enon, N.S.

A laboratory flotation study was successfully conducted on ore samples from the Lake Enon deposit. A celestite concentrate analyzing 97.5% $SrSO_4$ was obtained, with a recovery of 67.5% (9). Lake Enon ore has the advantage of the absence of fluorite, thus allowing celestite to be floated with

Table 4 – Summary of principal parameter data for celestite flotation, Cape Breton and Birch Island ores

Location	Head analysis %				Grind size µm	Rougher float min	Pulp density % solids	pH	No. of cleaner stages	Concentrate		Ref no.
	$SrSO_4$	SiO_2	$CaCO_3$	Fe_2O_3						Grade % $SrSO_4$	Distn %	
MacRae, N.S.	72.4	3.8	13.4	0.63	100%, –75	n.s.	33	7.0	4	94.4	79.0	11
MacRae, N.S.	71.2	4.5	13.5	0.50	100%, –150	n.s.	33	7.0	3	92.0	83.8	11
Lake Enon, N.S.	55.0	22.5	15.0	n.s.	n.s.	20	n.s.	n.s.	n.s.	92.0	95.0	8
Lake Enon, N.S	57.2	24.5	12.5	3.65	74%, –44	n.s.	20	6.0	4*	97.5	67.5	9
Lake Enon, N.S	41.6	11.4	40.4	1.80	80%, –75	n.s.	38	9.2	n.s.	88.6	70.5	16
Birch Island, B.C.	n.s.	–	–	–	100%, –44	2	n.s.	n.s.	3	84.5	78.0	7
Birch Island, B.C.	9.0	–	–	–	83%, –75	n.s.	n.s.	n.s.	2	81.1	n.s.	13
Birch Island, B.C.	14.5	–	–	–	98%, –75	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	17

n.s. – not stated

*Reground rougher concentrate to 97% –44 µm

Table 5 – Summary of reagent concentration data for celestite flotation, Cape Breton and Birch Island ores

	Scale of study	Collectors					Modifiers, Depressants				Ref no.
		Igepon g/t	Nyton g/t	T33/Oleic (3/1) g/t	A845*/Fuel oil (2/1) g/t	SAM** g/t	Na_2CO_3 g/t	Na_2SiO_3 g/t	Citric acid g/t	Oxalic acid g/t	
Rougher Flotation											
MacRae, N.S.	laboratory	–	–	–	–	300	–	1 200	–	600	11
MacRae, N.S.	pilot–plant	–	–	–	–	310	–	600	–	400	11
Lake Enon, N.S.	laboratory	1 300	–	1 500	–	–	–	–	–	–	8
Lake Enon, N.S.	n.s.	–	–	–	1 200	–	1 000	3 500	–	–	16
Birch Island, B.C.	n.s.	–	125	–	–	–	–	125	125	–	7
Birch Island, B.C.	n.s.	–	375	–	–	–	–	250	250	–	13
Cleaner Flotation											
MacRae, N.S.	laboratory	–	–	–	–	100	–	975	–	490	11
MacRae, N.S.	pilot–plant	–	–	–	–	100	–	600	–	300	11
Lake Enon, N.S.	laboratory	600	–	–	–	–	–	–	–	–	9
Lake Enon, N.S.	n.s.	–	–	–	250	–	–	1 250	–	–	16

*Aerofloat 845 – anionic petroleum sulphonate
**SAM – sodium alkyl sulphosuccinamide
n.s. – not stated

relative ease, while depressing quartz and calcite. Difficulties of a different nature, due to the collector Igepon T33, were later encountered when laboratory results were applied on a pilot–plant and, later, plant scale. Sodium oleoyl taurate (Igepon T33) was selective in laboratory investigations for celestite, but excessive frothing was encountered in plant trials (10). The use of oleic acid and isopropyl alcohol as froth modifiers controlled the excessive frothing but at the expense of reduced selectivity. Eventually Igepon T33 was replaced with Aerofloat 845, a petroleum sulphonate collector, which was as selective as Igepon T33 but less froth inducing.

MacRae, N.S.

Laboratory flotation studies conducted under the Canada/Nova Scotia Mineral Development Agreement (11) on MacRae ore, grading 70% $SrSO_4$ with 18% carbonates, minor quartz, galena and barite, demonstrated the technical feasibility of upgrading this ore to provide specification–grade feed for the conversion process. A pilot–plant run, based on the laboratory studies, produced a concentrate analyzing 90% $SrSO_4$ with 3.5% carbonates and 1.3% barite as the principal impurities. Recovery was 80 to 85%.

Laboratory conversion tests demonstrated the technical feasibility of the conversion of this product to glass–grade strontium carbonate, analyzing 99.0% $SrCO_3$. Several conversion processes, including both black ash and white ash, were evaluated to determine the most economic route for conversion.

Further information on studies by CANMET and other laboratories is included in the Appendix at the end of this report.

CONCLUDING COMMENT

This comment summarizes the feasibility of the development of Cape Breton celestite in light of world markets. It is essentially an abbreviated version of the Executive Summary of a 1985 study (18) of market economics of strontium minerals, which was carried out under the auspices of the Canada/ Nova Scotia Mineral Development Agreement.

Celestite ores containing more than 85% $SrSO_4$ are currently produced in 13 countries, with western–world production being concentrated in four small independent companies in Mexico, Spain, Turkey and England. There is no production in Canada or the United States at present. The current market for celestite worldwide is approximately 110 000 t. The manufacture of strontium compounds, the main end use of celestite, is showing positive growth, and most strontium–compound producers appear to be operating at or near capacity.

The United States and Japan have in recent years accounted for 45% and 30% respectively of strontium compound consumption, with Europe taking about 20%. The Canadian market is small; however, there is a shortage of strontium compounds in the United States and there is concern over the adequate future availability of celestite, which is almost entirely imported from Mexico. The chief U.S. consumer of celestite, Chemical Products Corporation, and its strontium compounds customers, such as RCA and Corning Glass, have all expressed interest in developing new sources of material. A Canadian source, such as the Lake Enon or MacRae deposits, would be particularly attractive in light of Canada's stability as well as its proximity to and close relationship with the United States. Because much of the celestite imported for processing in the other industrialized countries comes from less developed areas, an alternative Canadian source might be politically attractive for Europe and Japan as well.

The competitive advantage of the Lake Enon and MacRae celestite deposits lies largely in their location in an area of relative political and financial stability, close to the U.S. market. Additionally, an experienced nucleus of skilled labour is available on Cape Breton Island. On the other hand, the deposits have high production costs, relative to third–world competitors, because of low ore grade, complexity of mining and high labour costs. The practicability of celestite production would be particularly affected by transportation costs.

The feasibility of strontium compound production on Cape Breton Island would be less sensitive to labour and freight costs but would be adversely affected by the severe competition likely to be encountered from both established and new producers.

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APPENDIX

BENEFICIATION STUDIES OF CANADIAN CELESTITE DEPOSITS

Identification	:	N.S.-1 (Ref. No. 8)*
Report - Title	:	THE EFFECT OF PRIMARY SLIME ON THE FLOTATION OF LAKE ENON CELESTITE
- Author	:	F.A. Sinclair
- No. and Date	:	BSc Thesis, Technical University of Nova Scotia, 1974
Sample Description	:	30 kg; 55% $SrSO_4$, 22.5% SiO_2, 15.0% $CaCO_3$.
Mineralogy	:	Not stated.
Beneficiation	:	Flotation with and without slime (-5 μm material) to ascertain whether slime clay would be detrimental to flotation performance.
Results	:	The presence of large amounts of slime clay does not hinder the performance of the sodium taurate collector.
Remarks	:	The original pilot-plant test work, conducted at the Technical University of Nova Scotia, indicated that a grade of 92% $SrSO_4$ at 95% recovery could be obtained. The actual plant performance flotation circuit did not reach projected grades and recoveries. The relatively poor performance was attributed to scale-up factors and to the excessive frothing characteristics of the sodium taurate collector. Several froth modifiers were used to reduce frothing, including oleic acid, iso-propyl alcohol and actinol.

*CANMET indentification with Reference No. in brackets.

Identification	:	N.S.–2 (Ref. No. 9)
Report – Title	:	BENEFICIATION OF LAKE ENON CELESTITE, CAPE BRETON, NOVA SCOTIA
– Author	:	F.H. Hartman and R.A. Wyman
– No. and Date	:	Division Report 71–20 (IR), CANMET, Energy, Mines and Resources Canada, 1971
Sample Description	:	23 kg of celestite ore; 57.20% $SrSO_4$, 24.50% SiO_2, 12.50% $CaCO_3$, 3.65% Fe_2O_3.
Mineralogy	:	Principally celestite with quartz and calcite, minor mica and chlorite with trace dolomite and iron oxides.
Beneficiation	:	Fine grinding in two stages; primary grinding to 74% –44 μm with secondary grinding of rougher concentrates to 96.5% –44 μm. Magnetic separation to remove magnetics.
Results	:	A concentrate analyzing 97.5% $SrSO_4$, 0.31% SiO_2, 0.19% Fe_2O_3, 4.16% $CaCO_3$ was obtained, with a recovery of 67.5%.

Identification	:	N.S.-3 (Ref. No. 10)
Report - Title	:	LOCH LOMOND MILL START-UP: PROGRESS AND EVALUATION REPORTS
- Author	:	M.A.K. Grice
- No. and Date	:	Technical University of Nova Scotia, 1971
Sample Description	:	Mill feed (weight and analysis not stated).
Mineralogy	:	Not stated.
Beneficiation	:	Flotation of Lake Enon celestite evaluating the following variables: 1. variation between ore types, water and reagents, 2. influence of impeller speed and temperature, 3. pilot-plant evaluation of Aerofloat 845 as a substitute for Igepon T33, 4. the effect of oleic acid as a froth modifier when added with Igepon T33.
Results	:	No significant difference was noted between plant and pilot-plant ore types, water or reagents. The impeller speed profoundly influenced the rate of celestite flotation, such that an increased impeller speed resulted in a greater flotation rate. An increase in temperature increased flotation rate but to a lesser extent. Aerofloat 845 performed equally to Igepon T33, and oleic acid as a froth modifier reduced flotation selectivity.
Remarks	:	Metallurgically, the main problem in the plant was the inefficient performance of the roughers. Performance was improved to some extent by reducing pulp density from 40% to 20% solids. A decrease in pulp density, while maintaining the same feed rate, however, lowered the retention time. At 20% solids the retention time of 18.8 min was considered too low. Ideally the plant should have been designed around flotation cell surface area rather than retention time.

Identification:	:	**N.S.-4 (Ref. No. 11)**
Report - Title	:	**A STUDY OF THE MACRAE CELESTITE DEPOSIT, CAPE BRETON, NOVA SCOTIA**
- Author	:	**R.G. Williamson, Lakefield Research, Lakefield**
- No. and Date	:	**Canada/Nova Scotia Mineral Development Agreement, DSS No. 6-9031, 1987**
Sample Description	:	**70 t of -7 mm ore; 72.4% $SrSO_4$, 3.84% SiO_2, 13.4% $CaCO_3$, 0.63% Fe_2O_3**
Mineralogy	:	**Mineralogical examination showed that celestite was the major constituent with calcite, galena, sphalerite and pyrite in decreasing order of abundance. Electron-probe microanalysis showed that the barium was present in solid solution in the celestite; barite was not identified.**
Beneficiation	:	**Laboratory evaluation was carried out by grinding to -75 µm followed by de-sliming at 10 µm; bulk sulphide float was followed by celestite flotation of the sulphide rougher tailings; leaching of the celestite flotation concentrate reduced calcite level to <0.15% $CaCO_3$. Pilot-plant evaluation followed a similar route except that grind was to -150 µm.**
Results	:	**Laboratory evaluation produced a celestite flotation concentrate analyzing 94.4% $SrSO_4$ for a recovery of 79.0% under batch conditions; under cycle test conditions a concentrate analyzing 91.3% $SrSO_4$ was produced with a recovery of 83.4%. Pilot-plant evaluation produced a celestite concentrate analyzing 92.0% $SrSO_4$, 1.48% $BaSO_4$, 3.18% $CaCO_3$ and 0.54% SiO_2, with a recovery of 83.8%.**
Remarks	:	**A froth extender was required with the collector to control frothing. Regrinding reduced selectivity through slime production; selectivity rather than liberation was the controlling factor.**

Identification	:	N.S.–5 (Ref. No. 16)
Report – Title	:	MICROSCOPIC AND FLOTATION EVALUATION OF HIGH CALCITIC CELESTITE FROM THE MACRAE DEPOSIT, CAPE BRETON, NOVA SCOTIA
– Author	:	H. Hartjens – Consultant to Kaiser Celestite Ltd.
– No. and Date	:	1974 (not numbered)
Sample Description	:	Weight not stated; 41.6% $SrSO_4$, 40.4% $CaCO_3$, 11.4% SiO_2, 1.8% Fe_2O_3 and 1.3% $BaSO_4$.
Mineralogy	:	The liberation of celestite was essentially complete at 70% –75 μm, but inclusions of calcite persisted to a minor degree in celestite down to 30 μm.
Beneficiation	:	Grinding to 80% –75 μm followed by celestite flotation evaluating: 1. Na_2CO_3 and Na_2SiO_3 reagent concentration, 2. controlling water hardness, 3. pre–flotation of galena before celestite.
Results	:	Varying the concentration of Na_2CO_3 and Na_2SiO_3 did not noticeably influence the rougher concentrate grade, but the highest recoveries corresponded to the highest addition levels of these reagents. While employing four cleaning stages, a celestite concentrate analyzing 88.6% $SrSO_4$, with 70.5% recovery, was obtained.